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DISCUSSION
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DISCUSSION OF A COMPARISON OF DESIGN METHODS FOR AIRFIELD PAVEMENTS PROCEEDINGS-SEPARATE NO. 163

L. A. PALMER.[14]—Pending the time that many direct comparisons are made available by simultaneous applications of all the procedures to the same airport paving projects, the Committee on Correlation of Runway Design Procedures has extracted a maximum of information from the paucity of poorly correlated data existing at the time of its progress report.

[14] Eng. Consultant, Soil Mechanics and Paving, Bureau of Yards and Docks, U. S. Dept. of the Navy, Washington, D. C.

In the use of the method of trial pavement sections by the Bureau of Yards and Docks, United States Department of the Navy, the theoretical approach as developed by Mr. Burmister is recommended for obtaining a first approximation of the required flexible pavement thickness. In the final analysis, the recommended pavement thickness for any given tire load and for any given tire pressure must depend on the measured settlements obtained by plate loading (see under the heading, "The Navy Method") on the trial sections having thickness equal to, less than, and greater than, the theoretical value. By this method, the materials, compacted densities, and moisture contents of the subbase and base course materials of the trial sections must be the same in all test sections, and the subgrade must be the same with respect to type, depth, and degree of compaction and moisture content throughout. The only variable is pavement thickness. Moreover, the construction of the trial sections must conform to the specification requirements that are to govern and apply in the construction of the runway, taxiway, or other pavement.

The Navy method is more "sensitive" to the effect of tire pressure on the wheel load capacity of pavements than is the CBR method described in the report. There is considerably less divergence between CBR-thickness design curves for tire pressures of 100 lb per sq in. and 200 lb per sq in. than corresponds to differences in required pavement thicknesses for these two tire pressures as estimated by the Navy method (see Figs. 8, 20, and 21).

Fig. 27 is a comparison between the actual pavement thicknesses as determined on new construction projects during the past three years by the Navy method (lower curve) at ten naval air stations and the corresponding thickness (upper curve) for the same subgrades at the same ten naval air stations, using the CBR method. The tire loading in this comparison is 50 kips on a single tire at a tire pressure of 150 lb per sq in. The upper curve in this figure relates CBR and thickness and was obtained by interpolating between the two CBR design curves for 50 kips at tire pressures of 100 lb per sq in. and 200 lb per sq in. The greatest divergence between the two curves of Fig. 27 is for a soaked CBR of 3 (the lowest value), for which the estimated thickness by the Navy method is 35 in. and that obtained by the CBR method is approximately 43 in. For CBR-values exceeding 10, the estimated thicknesses by the two methods tend to be more nearly equal. At these ten naval air stations, data for soaked CBR samples were made available. Unfortunately, such data were not obtained at thirty eight other naval air stations where the trial section method was applied on a considerable scale. Usually, application of both methods is impracticable when time and funds for testing are limited.

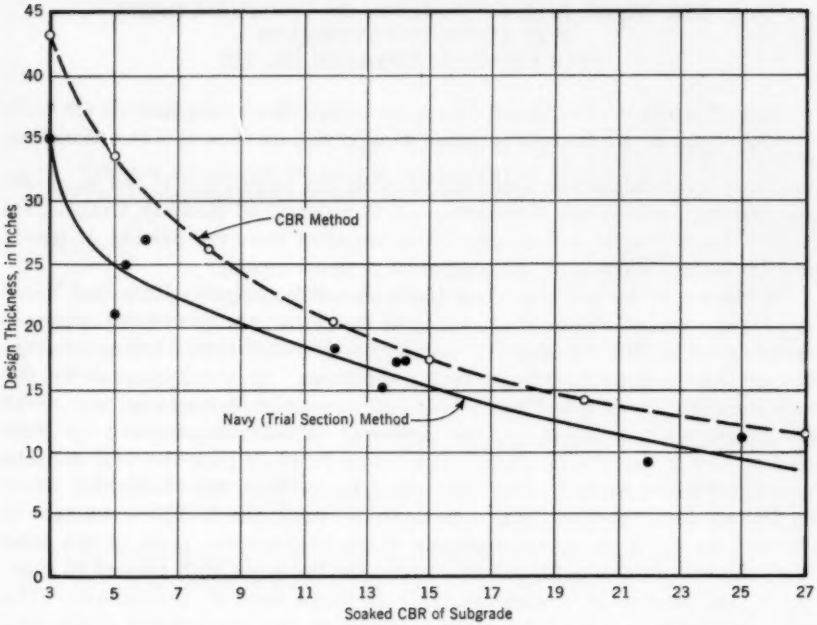

FIG. 27.—A COMPARISON OF FLEXIBLE PAVEMENT THICKNESSES AS DETERMINED BY TWO PROCEDURES (50-KIP TIRE LOAD AT A TIRE PRESSURE OF 150 LB PER SQ IN.)

The CAA method may be called the "comparison method." Many state highway departments use this method. The rapid development of new types of military aircraft render this method less adaptable to military airports than to commercial airports. This method seemingly has no reference to tire pressure. In Navy experience, at least, the safe maximum tire-load rating of a given pavement decreases generally as the tire pressure increases, all other factors being the same. Stated in another way, for any given tire load the required pavement thickness is greater for relatively high tire pressures than than for relatively low tire pressures, all other conditions being the same.

The Canadian, Navy, and Corps of Engineers methods all involve loading tests, since actually the CBR test is a miniature loading test. In-place CBR tests tend to be very erratic for this reason. Repetitive loading (Canadian method) tends to produce progressive compaction of materials. With greater initial compaction (100% of maximum density by the modified AASHO method), the nonrecoverable deflection by repetitive loading becomes less.

From the standpoint of the cost of pavement maintenance, taxiways, aprons, and turnaround areas require greater pavement thickness than do runways. However, there is the added consideration that an accident caused by an underdesigned runway pavement involves much more than the cost of patching the pavement. Runway failures are hazardous to human life and to costly planes, and the cost of immobilizing a military airport because of pavement failures in runways during a period of all out war cannot be estimated.

FRANK H. GARDNER[15] M. ASCE.—There are both merits and deficiencies in all the methods presented. The CAA method is based on easily established soil properties that are of proven value. The classification of a soil, based on gradation, liquid limit, and plastic limit, can be definitely determined. From this classification and a knowledge of the frost and drainage conditions, the factors are obtained for entering the appropriate curves. From these curves the surface, base, and subbase thicknesses for the wheel loads involved can be determined. The thickness of the surface courses, from Figs. 3 to 7, are rather thin—but the total of the surface, base, and subbase thicknesses give a safe and economical design. The CAA method for the design of rigid pavements is to be commended, especially for the provision for a granular base under the concrete slab.

[15] Chf., Grounds Section, Headquarters MATS, U. S. Air Force, Washington, D. C.

The CAA method, like most other methods, does not furnish a definite manner for designing the thickness of the various courses, nor for the blending of the various materials which might be economically available for the base and subbase courses. A case in point would be the existence of a local material which could be used "as is" in lower layers, but would need blending with higher grade material near the top of the base or subbase. Much more research is needed on the strength required for the base and subbase layers in order to provide for the proper transition between the surface and the subgrade. An attempt in this direction is made in the CBR method. From Figs. 8 and 9, the required CBR at any depth below the surface may be determined. The weakness of this method lies in the fact that it does not permit reliable determination of the CBR-value of the layer increments required.

The CBR method, based on the CBR-value of the subgrade soil and the various layers of the base, has been presented.[3] The principal weakness of this method lies in the nonuniformity of the test results. The system is excellent if a reliable CBR-value for the soil and base materials can be established. It appears, however, that much more research is needed to perfect the testing procedure and to assure uniform correlation with the fundamental soil properties.

[3] "Development of CBR Flexible Pavement Design Method for Airfields: a Symposium," *Transactions*, ASCE, Vol. 115, 1950, p. 453.

To improve the usefulness of the CBR method it is necessary to determine proper moisture content—probably between the plastic and liquid limits of plastic soils—at which the CBR-value should be taken. When this is done, it is probable that reliable relationships can then be established between the CBR-value, the group index, the angle of internal friction, and other properties of the soil. Another step toward the improvement of the usefulness of the CBR method would be the perfection of a reliable method for determining the CBR-values for granular materials with coarse aggregate and variously stablized coarse graded base mixtures. Until these two steps are taken, the CBR method must be used with care and judgment.

Both the Navy method and the Canadian method are primarily based on plate bearing tests which, like the CBR tests, are subject to nonuniformity.

This nonuniformity is caused by the method of performing the test, and the compaction and moisture content of the soils. The provision for test sections, in the Navy method, is good, but a weakness in the method is that the design is based on bearing tests made before the ultimate equilibrium of the moisture-density ratios for the soil is reached.

The Canadian method, although a valuable contribution to the field of plate bearing tests, is burdened with the inherent defects in the bearing test approach to the design problem. Under further research and analysis, the plate bearing methods might contribute considerably to the solution of pavement design problems. At present, however, these methods must be used with caution and good judgment. Plate bearing tests are probably best utilized in the design of pavement overlay.

G. M. J. WILLIAMS,[16] A.M. ASCE.—Under the heading, "Comparison of Design Procedures: Bases for Comparison," the following appears:

[16] Senior Asst. Engr., Scott and Wilson, Hong Kong.

> "* * * the moisture content and the state of compaction of a subgrade are both subject to change subsequent to the construction of a pavement, and that changes in either of these factors may involve a serious alteration in the stability of the pavement. Therefore, in designing pavements it is essential to estimate the critical condition of moisture at which the supporting capacity of the subgrade should be determined."

Unfortunately, although many methods have been developed for determining the thickness of the pavement required upon a subgrade of a given supporting capacity, there are no generally accepted methods of estimating the critical condition of moisture in a subgrade, or what its supporting capacity will be at that moisture content.

The paper reviews all of the important methods of pavement design, and while the methods of determining the pavement thickness are based on thorough mathematical analyses and experimentations, they all require some estimate to be made of the strength of the subgrade. Carefully devised methods are described for measuring the strength of the subgrade at the time of construction, but only very crude methods are available for estimating to what extent that strength will be reduced by subsequent softening caused by an increased moisture content after construction. For example, the Westergaard method and the Navy method, as normally used, make no allowance for this effect; the CAA method allows only for a distinction between "good drainage" and "bad drainage" and the Canadian method allows only for softening inasmuch as the tests upon which it was based were made on pavements which had been built for several years. The CBR method originally allowed for softening by specifying that the sample should be soaked for four days under a small surcharge. This reproduces the worst conditions which could occur (ground water level above the top of the subgrade) but such conditions should never occur on most sites and most designers make arbitrary modifications to the method by reducing the soaking time, increasing the surcharge weight, or reducing the pavement thickness by an arbitrary factor. There seems to be no reason for developing more accurate methods of pavement design until reliable methods are available for estimating the extent to which the subgrade will soften and become weaker after construction is complete.

The writer considers that a method of estimating the ultimate maximum moisture content of the subgrade could be developed as follows: If it is assumed that the runway surface is waterproof, the moisture content of the subgrade can only increase by horizontal permeation from the sides, by water rising from below, or by water condensing from water vapor in the air-voids. Efficient side drains should prevent water soaking horizontally into the subgrade from the sides, and analytical methods are available[17] for the determination of the

[17] "Soil Mechanics for Road Engineers," Her Majesty's Stationery Office, London, England, 1952, Chapter 16, p. 293.

maximum amount of moisture which a given soil will retain from moisture which has condensed out of the air-voids or which has risen from the subgrade. This amount of moisture depends on the following factors: (1) The highest level to which the ground water level is likely to rise, (2) the temperature of the subgrade, (3) the temperature gradient under various conditions, and (4) the moisture suction of the soil. Methods are available[18] for laboratory measure-

[18] "The Suction of Moisture Held in Soil and Other Porous Materials," by D. Croney, J. D. Coleman, and Pamela M. Bridge, *Road Research Technical Paper No. 24*, Her Majesty's Stationery Office, London, England, 1952.

ment of the moisture suction of various subgrade materials, and reasonably accurate estimates can be made for the other factors. Thus it is possible to estimate the maximum increase in moisture which might be expected in subgrade under given conditions and consequently the probable reduction of strength as a result of softening can be determined. Methods of pavement design, such as the Westergaard method or the CBR method, can then be used with greater assurance.

CHARLES R. FOSTER,[21] A.M. ASCE.—The difficult task of correlating the

[21] Engr., Chf., Flexible Pavement Branch, Soils Div., Waterways Experiment Station, Corps of Engrs., U. S. Dept. of the Army, Vicksburg, Miss.

various methods of pavement design has been commendably accomplished. The authors clearly state that the development of a design method for pavements is comprised of (1) the determination of thicknesses, of both the pavement and the base, to be used when the subgrade strength is known, and (2) the development of laboratory procedures for compacting a sample of the subgrade and adjusting its moisture content, or otherwise treating it, so that the sample's strength will be the same as the constructed subgrade when the subgrade is adjusted to a final moisture condition. Pertinent investigations of flexible pavement design are being conducted (1953) by the Corps of Engineers and these will be discussed.

The CBR design curves used for single wheels with tire pressures of 100 lb per sq in. have been confirmed by adequate supporting data. The CBR design curves used for single wheels with tire pressures of 200 lb per sq in. and for multiple wheels are based primarily on the 100-lb-per-sq-in., single-wheel curves, theoretically adjusted as described in the symposium on the development of the CBR method.[3] Limited traffic-testing for validation of these theoretical adjustments has been completed and the results of the traffic-testing agree reasonably well with the theoretical adjustments.

The procedures used by the Corps of Engineers in the preparation of samples for the design test admittedly do no provide a perfect answer. In most cases conservative values are obtained. The four-day soaking procedure is not required where more reliable information is available. For example, in the redesign or extension of existing pavements, the in-place CBR-value of the

subgrade under the existing pavement is generally used for the design of the new pavements. These values are used if the existing pavements have been in place long enough for the moisture and density conditions to have become adjusted to the conditions of climate and traffic. The in-place CBR-value is also used for evaluation of existing pavements. Criteria have been established to determine when the in-place values can be utilized. However, some judgment must be used to be sure that the in-place values are applicable. As further evidence of the importance placed on moisture conditions, the Corps of Engineers permits a 20% reduction in design thicknesses in arid regions to compensate for less severe moisture conditions. This is a substantial reduction, amounting to an approximately 40% increase in load.

Procedures have been devised for the design of "theater-of-operation" fields, where the life of the field is short. These procedures are based on the "as-molded" CBR-value without soaking.

The Corps of Engineers is working (1953) toward a more rational method for the design of airfield pavements. This program, which is a considerable part of the total investigational effort in the design of flexible pavements, consists of the construction of test sections with embedded pressure cells and strain gages. Loads are applied and the stresses and strains are plotted. Undisturbed samples are taken where possible, and various types of triaxial tests are conducted in attempts to produce laboratory stress-strain curves equal to field stress-strain curves. When methods of computing the actual stresses and strains in the subgrade under load are developed—when a test that will give stress-strain curves approximating the field curves is evolved—and when laboratory samples can be prepared to simulate future field conditions, progress toward a more rational method of design will be possible. Until then, information gained from studies of these types permits theoretical adjustments of the empirical design procedures for various loads, tire pressures, and wheel assemblies.

HOWARD M. MCMASTER,[19] J.M. ASCE.—An excellent study of the different design procedures for both flexible and rigid type pavements has been presented in this paper. The authors are to be commended for a comprehensive comparison and correlation of a difficult subject. An examination of the material may be made with a a minimum of effort.

[19] Asst. Prof., Civ. Eng., Univ. of Nebraska, Lincoln, Nebr.

It is believed that in the interest of clarity, some modification might be made under the heading, "Comparison of Design Procedures: Comparison of Rigid Pavement Design Methods," wherein a study is made of the CAA method and the Westergaard analysis. Specifically, the basis for comparison of the two design approaches is the use of a value of k equal to 300 lb per cu in. for both analyses. No information is given about the derivation of the CAA design method except that the variable thickness of the subbase will produce the constant k-value of 300 lb per cu in.

In Fig. 26, the CAA method (involving an undetermined factor of safety) is compared with the Westergaard theory—using a factor of safety of 1.5. The only information available concerning the basis of the CAA design is provided in the following[20]:

> "In all cases, pavements that were inadequate to support, without failure, the applied loads had thicknesses less than those required by the R_1 curve."

[20] "Airport Pavement Performance," *Airport Engineering Bulletin No. 2*, CAA, Dept. of Commerce, Washington, D. C., April, 1952, p. 7.

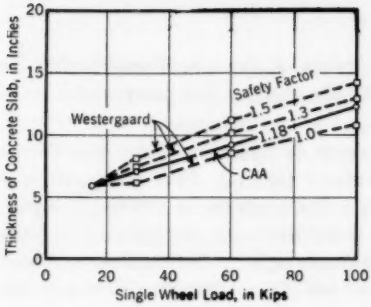

FIG. 28.—COMPARISON OF RIGID PAVEMENT DESIGN

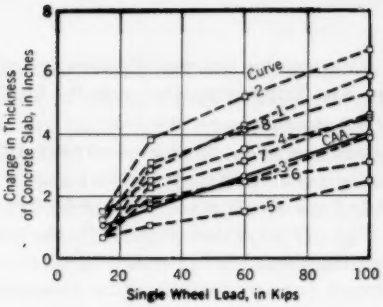

FIG. 29.—CHANGE IN PAVEMENT THICKNESS AS A RESULT OF A CHANGE IN LOADING

It is believed that to present a clearer picture of what is involved, the comparison should be made on the basis of superimposed curves which would eliminate the possible misinterpretation of the CAA method offering a thinner pavement than the Westergaard theory with apparently equivalent conditions.

The physical presentation of these suggestions might be made as shown in Fig. 28, where curves conforming to the Westergaard theory for the various factors of safety are shown in comparison with the CAA-method curve, in the same manner as Fig. 26. Reference to Fig. 28 indicates that a Westergaard curve with a factor of safety of 1.18 will result in a curve corresponding to the CAA curve.

An examination could be made of the change in thickness found by both methods when considering the design of runways and the ends of runways and taxiways. Consideration of Fig. 29 indicates that the change in thickness between the two locations, utilizing the CAA method, is 1 in. for a wheel load of 15 kips and 4 in. for a wheel load of 100 kips. The corresponding changes by the Westergaard theory depend on the factor of safety involved. These changes are illustrated by an examination of Fig. 29 which was drawn using the following safety factors:

Curve number	Taxiway and runway ends	Runway
1	1.8	1.0
2	2.0	1.0
3	1.8	1.3
4	2.0	1.3
5	1.8	1.5
6	2.0	1.5
7	1.8	1.18
8	2.0	1.18

Curve 1 shows a change in thickness of 0.7 in. for a wheel load of 15 kips and a change of thickness of 5.9 in. for the 100-kip wheel load. Since the PCA's suggested range of safety-factor values is from 1.8 to 2.0 for runway ends and taxiways, these extremes were compared to the suggested and selected values of safety factors for the center sections of runways. To complete the illustration, Curve 2 is the comparison of taxiway safety factor 2.0 with safety factor 1.0 for the central section of runways. This curve shows a change in thickness of 1.5 in. for the 15-kip wheel load and 6.7 in. for the 100-kip wheel load.

The remaining curves illustrate similar comparisons using the various combinations of safety factors. Obviously, the use of the safety factor of 1.0 is for comparison purposes only, since it would normally not be used in design.

Curves 7 and 8 are drawn using a safety factor of 1.18, corresponding to the CAA design curve shown in Fig. 28.

COMMITTEE ON THE CORRELATION OF RUNWAY DESIGN PROCEDURES OF THE AIR TRANSPORT DIVISION.[22]—In Fig. 27 Mr. Palmer has presented a comparison between flexible-pavement thicknesses as determined by the Corps of Engineers' (CBR) procedure and by the Navy method. The comparison is made for a single wheel load of 50,000 lb at a tire pressure of 150 lb per sq in. In Figs. 24(*d*), 24(*e*), and 24(*f*), the curves show the same comparison, but the tire pressure is 100 lb per sq in. instead of 150 lb per sq in.. Nevertheless, it is of interest to compare the actual thicknesses at ten Navy airfields (shown as the solid line in Fig. 27) with the Navy thicknesses computed from correlating CBR-values with E_2 (shown as the dashed line in Fig. 24):

[22] Walter Johannessen, *Chairman*.

CBR rating of subgrade	50-kip single wheel load, Fig. 24	Thicknesses in inches, Fig. 27
3	39	35
8	19	21.5
15	13	15

The thicknesses obtained from Figs. 24 and 27 compare favorably with each other when one considers the fact that the thicknesses from Fig. 27 are for a tire pressure that is 50 lb per sq in. greater than the thicknesses determined from Fig. 24. For CBR-values of 8 and 15, Fig. 24 gives slightly lower values than does Fig. 27, as it should because the tire pressure is less. For a CBR-value of 3, however, there appears to be an unexplainable discrepancy; Fig. 24 gives a greater value than Fig. 27. In general, Mr. Palmer's presentation gives evidence that the Navy thicknesses, as determined by the Committee from a correlation with the CBR method, are of the proper order of magnitude.

Mr. Gardner states:

> "* * * The principal weakness of this method [CBR] lies in the nonuniformity of the test results. The system is excellent if a reliable CBR value for the soil and base materials can be established. It appears, however, that much more research is needed to perfect the testing procedure and to assure uniform correlation with the fundamental soil properties."

The Committee is not aware of the fact that CBR tests yield more nonuniform results than other tests. Generally, the CBR of a fine-grained soil can be reproduced with a fair degree of accuracy. It is true that the reproduction of field conditions in the laboratory is a difficult task, but this applies to all other laboratory tests and is not confined to the CBR procedure. The CBR test is an empirical one, used in conjunction with an empirical correlation between CBR-values and the required thickness of pavement to support specified traffic —as determined from traffic tests. There is no particular need to correlate CBR with the fundamental soil properties because the CBR test would never be used for a precise determination of these properties. Mr. Gardner also suggests that the procedure for determining the CBR of granular materials with coarse aggregate needs improvement. At present (1954) the CBR test permits coarse aggregate up to a maximum of $\frac{3}{4}$ in. to be placed in the mold. Larger size aggregate must be discarded and replaced with an equivalent amount of smaller aggregate. It is true that discarding aggregate larger than $\frac{3}{4}$ in. in diameter undoubtedly affects the CBR-values; however, this is not too critical, because it is the presence of very fine material in an aggregate mixture that will cause a reduction in CBR-values.

Mr. Williams has made an interesting point—one that is much discussed. For lack of knowledge of the specific amount of moisture that would occur under a pavement subsequent to its construction, many agencies are assuming the worst condition—all the soil voids to be filled with water. While the Committee agrees that it would be desirable to be able to estimate the moisture condition under a pavement, there is some question whether it can be done at this time (1954) to any reasonable degree of accuracy, considering the factors that must be known. This, however, is a subject worthy of continued study by engineers concerned with the field of pavement design.

Mr. McMaster has made an important point concerning the application of the Westergaard analysis or formula to the design of rigid pavements: It is necessary to determine what factors to apply, so that a pavement design based on the theoretical concepts of the formula can be correlated with the requirements as determined by observations of pavement performance. It is pavement performance that is the backbone of the CAA method of estimating the pavement thickness required for a specified wheel load.

The CAA recognizes the analytical method of Mr. Westergaard in the design of rigid pavements but has found (from studies of pavement behavior) that under normal conditions, using materials and methods of construction that conform to specification requirements, the required pavement thicknesses can be determined from the curves presented in Fig. 3. In the development of these curves certain average values are assumed as follows: Flexural strength of concrete—between 600 lb per sq in. and 700 lb per sq in.—or an average of 650 lb per sq in.; modulus of elasticity of concrete—4,000,000 lb per sq in.; Poisson's ratio—0.15; tire inflation pressure—100 lb per sq in..

Also, performance studies have disclosed that it is good engineering practice to place a layer of selected subbase material under the rigid pavement when the subgrade consists of a plastic soil. Using a variable thickness of subbase, depending on the character of the soil and the applied wheel loading, it is considered reasonable to estimate a modulus of subgrade reaction, k, equal to 300 lb per cu in. This does not mean that such a value will be obtained if a plate loading test is performed in the usually prescribed manner. It does mean that the provision of a subbase will have the same effect, within practical limits, as a k-value of 300 lb per cu in. when the pavement thickness requirement is determined by use of the Westergaard theory. Ordinarily, plate loading tests would give results varying considerably from this figure. Nevertheless, observations on civil airports show that pavements giving satisfactory performance have thicknesses that agree with computed thicknesses when a k-value of 300 lb per cu in. is used—provided other factors used in the design are also selected in accordance with data furnished by service records. Considering the problems involved in the determination of k, this estimate is believed to be as reliable as the data obtained from plate loading tests.

Although tire pressures may vary from a pressure of 100 lb per sq in. and computations by use of the Westergaard formula will show slight changes in thickness requirements, the variation within the normal range of tire pressures for air-carrier operations (from 75 lb per sq in. to 120 lb per sq in.) have little significance in the structural design of pavements. Tire pressures of 200 lb per sq in. may require further consideration.

Mr. McMaster has shown that the CAA curve for runway pavements corresponds to a factor of safety of 1.18 when applying the Westergaard theory. This factor of safety, 1.18 or 1.2, should be perfectly satisfactory for runway design. It will be found that a factor of safety of approximately 1.6 will be suitable for taxiway, apron, and runway ends.

Mr. Foster has presented some information which is of interest to those who have advocated that the four-day soaking procedure, followed by the Corps of Engineers in the CBR test, yields conservative values of pavement thickness in certain localities. Mr. Foster states that

> "The four-day soaking procedure is not required where more reliable information is available. For example, in the redesign or extension of existing pavements, the in-place CBR-value of the subgrade under the existing pavement is generally used for the design of the new pavements."

The problem of forecasting, with any degree of accuracy, the "worst" moisture condition in a subgrade and the pavement components during the life of a pavement is a difficult one; nevertheless some progress is being made in this direction. As more data become available and the mechanics of moisture movement are more fully understood, a closer approximation of the "worst" condition may be possible.

In conclusion, it should be emphasized that all methods of pavement design involve many assumptions and factors which, up to the present time (1954), have not been evaluated with sufficient accuracy to provide a completely satisfactory design formula. For this reason, pavement performance must continue to serve as a guide to pavement design; and good judgment, as well as tests and stress analysis, must be relied on to evaluate properly the factors used in design.

JAMES L. FOLEY, Jr.,[3] A. M. ASCE.—A lucid description of the role of the engineer in solving one of the most vexing of city planning problems has been presented by Mr. Braff.

[3] Traffic Engr., J. E. Greiner Co., Cons. Engrs., Baltimore, Md.

Implied, but not emphasized, by the author are two important functions which are (or should be) the traffic engineer's responsibility. Public parking facilities and mass-transit service are such integral parts of the street transportation system that the engineer should exercise a considerable influence on their design and operation. This influence may be exercised directly if the engineer has full responsibility within his organization, or indirectly, through interdepartmental coordination.

The rapid growth in motor-vehicle registration during the period following World War II indicates the necessity of obtaining the greatest traffic efficiency possible within the existing rights of way. To achieve this end, it appears that rush-hour parking eventually will have to be prohibited on most major thoroughfares.

As stated by the author (under the heading, "Immediate Program: Operations") regulation of curb parking is one of the devices available to the engineer for improving the efficiency of a street system. In spite of the obvious advantages of the elimination of curb parking, the engineer often must "sell" good engineering practices to the laymen in a municipal government. In addition to the regulation of curb parking, the traffic engineer should approve the functional design of off-street parking facilities. It is imperative that the engineer review and approve the plans for all off-street facilities because operational defects (such as lack of adequate reservoir space or poor entrance design) can reduce the efficiency of a street as greatly as does curb parking.

It is obviously impossible for most cities to provide all the parking space likely to be required in the future. To meet this need for space, close cooperation is required between the various engineers charged with the responsibility of determining and planning for future traffic. If based on sound criteria, zoning regulations give some assurance that in the new growth and redevelopment areas of cities the streets will be available for the movement of traffic. Additional studies are necessary to provide data for determining sound criteria. J. T. Thompson, M. ASCE, and J. T. Stegmaier, J. M. ASCE, have suggested a method of obtaining these criteria from origin-destination studies.[4]

[4] "The Effect of Building Space Usage on Traffic Generation and Parking Demand," by J. T. Thompson and J. T. Stegmaier, *Proceedings*, Highway Research Board, National Research Council, Washington, D. C., Vol. 28, 1948, p. 320.

Before the Chicago (Ill.) zoning ordinance was revised to require adequate off street parking facilities, studies were made of the parking needs of various land uses. The results of these studies were incorporated in the proposed revision to the zoning ordinance.[5] This ordinance is a good example of interdepartmental coordination in that the studies and recommendations were the result of the joint efforts of the Bureau of Street Traffic of the Chicago Plan Commission, and other interested departments.

[5] "Proposal for Amendment of Chicago Zoning Ordinance in Reference to Off-Street Parking Facilities," *Committee Pamphlet No. 15*, City Clerk, Chicago, Ill., July, 1953.

Transit.—Adequate off-street parking, improved traffic-control devices, grade separations at major intersections, and similar remedial measures do much to improve the flow of traffic. It appears, however, that mass-transit service must be provided (at least in the larger cities) if such cities are to continue to exist as at present (1953). A city's reliance on mass transit is a direct function of the city's size. Some major cities have struggled along without transit service for short periods of time. Detroit (Mich.) is one of the largest cities to have done so. However, certain cities (such as New York, N. Y., Chicago, and Boston, Mass.) would be practically paralyzed by the lack of mass-transit facilities. It is physically impossible to park the number of passenger cars that would be required to transport the people normally present in the central business districts of these cities.

It behooves the traffic engineer, in planning adequate highways, to do all that possibly can be done to encourage general use of mass transit and to assist the transit company in its efforts to provide convenient, expeditious service. The traffic engineer should promote the type of long-range planning which makes adequate provision for mass-transit service.

LLOYD BRAFF[6].—The writer finds no point of controversy in Mr. Foley's discussion. No questions were raised, and further expository material is not required. Hence, no further comment will be added.

6. City Traffic Engr., Dallas, Tex.

LOUIS A. NEES,[3] A.M. ASCE.—The writer concurs in the author's opinion concerning intersecting runway patterns. The development of heavier aircraft with more stability against beam winds, and the development of cross-wind landing gears, tend to eliminate the necessity for intersecting runways that provide for all possible wind variations.

[3] Chf., Eng. Branch, Installations Div., Headquarters Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio.

Table 2 would be increased in value if it were expanded to indicate the type of aircraft for which the size determinations are listed. It does not seem probable that Table 2 could be applied to a wide range of aircraft types.

The writer would question the author's statements regarding the drawbacks in the present (1953) design methods for aircraft pavements. It is true that design guides are generally empirical. However, to a great extent, the criteria (especially those adopted by the Corps of Engineers) are the result of extensive and continuing correlation with tests and analyses of existing pavements. It is extremely possible that a theoretical analysis can never determine subgrade strengths and pavement thicknesses. Judgment and experience must always play a major part in this particular type of design. However, the progress made (by various governmental agencies) in improving design procedures has resulted in logical and reliable methods of pavement design.

Mr. Hahn states that the spillage of jet fuels is not a serious problem, but he considers that the effect of the jet blast is significant. On the basis of the writer's limited experience with pavements subjected to both of these factors, it is believed that the reverse is true. The jet-blast effects appear to be significant only while the airplane is stationary; deterioration of the pavement is appreciable only on asphaltic types of construction and on seeded shoulders. In military operations, these problems have been solved by the use of portable blast deflectors and by the provision of appropriate stabilization in areas where warm-ups would otherwise cause erosion of the shoulders. Moreover, the use of Portland-cement concrete in such areas eliminates a great many of the problems connected with jet blast. Spillage, however (as a result of the relatively low volatility of the fuels), can be a significant factor—especially on aprons and work areas where the pavements are constructed of asphaltic concrete. In the writer's opinion, there has not yet (as of 1953) been produced an asphaltic pavement which provides any reliable resistance to damage from spillage of jet fuels. It is in this field that continuing study and development are especially needed if bituminous pavements are to compete satisfactorily with Portland-cement concrete.

It is noted that the author makes no mention of the problem of noise suppression and control. With the advent of increased traffic and higher-powered, jet-engine-propelled aircraft this factor becomes an important one, not only in the effect on surrounding areas but also in the effect on workers engaged in the maintenance and overhaul facilities. Considerable strides in the study of this problem have been made both by aircraft manufacturers and by the